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Profile of Total Energy Use for U.S. Industry

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Energetics, Incorporated
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Office of Energy Efficiency and Renewable Energy

Industrial Technologies Program

Preface

Energy is a critical resource for U.S. industry. It provides fuels and power to drive industrial processes, as well as raw materials for a myriad of industrial and consumer products. As an essential resource, the availability and cost of energy can significantly impact industrial competitiveness and growth. The use of energy also creates a burden on the environment through the emission of air pollutants and greenhouse gases such as carbon dioxide and methane. Industry must continuously balance the challenges of energy, economics and environment to maintain a competitive edge in the global marketplace.

The Industrial Technologies Program (ITP) at the U.S. Department of Energy (DOE) supports cost-shared research programs to encourage the use of energy efficient, clean manufacturing technologies in U.S. industries. Working closely with industrial partners, national laboratories, and academia, ITP is accelerating the use of advanced technologies that can provide energy, economic and environmental benefits for industry and the nation.

This report examines the total use of energy within the industrial sector, and the associated carbon emissions. The objective is to identify and compare energy use among various industry groups, and to illustrate the quantity and type of energy resources currently in use. This comparative analysis provides ITP with a perspective on potential targets for the development and implementation of advanced, energy efficient technology.

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1.0 Overview of U.S. Industry Groups

The U.S. industrial sector is a critical component of the U.S. economy, providing the finished goods and materials for buildings, transportation, and consumer products that are essential to our quality of life. Industry is inherently diverse, relying on thousands of complex, technology-driven processes to create millions of different products. As Figure 1-1 illustrates, industry groups are also integrally linked, with some providing raw materials, others manufacturing basic building blocks and intermediates, and still others performing various finishing, forming, and fabricating functions.

Table 1-1 Industry Categories	
Materials	Mining, Oil and Gas Extraction, Agriculture
Basic Manufacturing	Aluminum and Alumina, Cement, Chemicals, Food Processing, Forest Products, Glass And Glass Products, Iron and Steel Mills, Petroleum Refining
Forming and Finishing	Fabricated Metals, Foundries, Forging, Heat Treating, Powder Metallurgy, Welding
End-Users	Computers, Electronics, Appliances and Electrical Equipment, Construction, Heavy Machinery, Textiles, Transportation Equipment, Plastic and Rubber

For this report, U.S. industry has been divided into four categories that illustrate the chain of supply and demand throughout industry, from raw material to finished goods. Table 1-1 identifies the industries contained within each category. These categories -- ***materials, basic manufacturing, forming and finishing, and end-users*** -- correlate to the essential functions performed by each industry group. Mining, for example, provides essential raw materials to the aluminum and steel industries, who use them to manufacture intermediate products that are then sent on to forming and finishing industries to be fabricated, forged or cast.

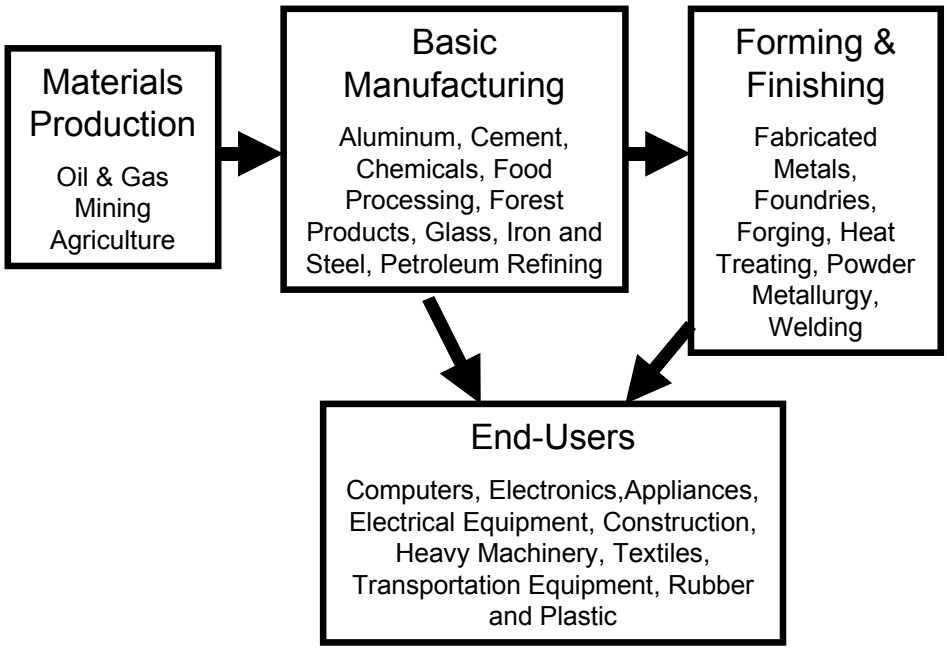

Figure 1-1. Interrelationship of Industry Groups

In some cases, the lines between industries are not clearly defined. Welding and heat treating, for example, are conducted in many industries, and are considered to be "cross-cutting." Glass melting may be performed in plants dedicated to that purpose, or may be one of many sub-industries dedicated to a larger manufacturing complex (e.g., flat glass in an automobile plant). In all cases, industries in different categories are solidly interconnected, and would not exist without these links.

Materials

The materials sector includes industries involved in production of the raw materials needed to manufacture goods. **Mining** provides mineral and non-mineral inputs taken from the earth, such as iron ore for steel making, bauxite for aluminum making, and phosphate for fertilizers. **Oil and gas extraction** involves the production of energy resources that are used for both fuels and feedstocks for chemicals and material products. Agriculture provides biomass for food and feed as well as a variety of other products (e.g., adhesives, pharmaceuticals).

Basic Manufacturing

The manufacturing sector produces building blocks and intermediates for industrial products as well as finished goods for both industrial and consumer use. These industries, which are often referred to as the **basic or heavy industries**, are a central link for the production of most of the finished products we use today. Without them, items that are integral to everyday life, such as our homes, automobiles, clothing, computers, tools, and appliances, would not be possible. The forest products industry, for example, provides lumber that is used to create furniture and building materials, and paper for books and magazines. Petroleum refineries provide fuels as well as the chemicals needed to produce plastics, food, pharmaceuticals, paints, toiletries, soaps and detergents, and a host of other products. Most of the basic manufacturing industries create final products as well as intermediate products that must be further processed or finished before becoming useable.

Forming and Finishing

The forming and finishing sector includes industries that perform a variety of physical operations to create both finished products and intermediates from a variety of inputs. The **fabricated metals** industry creates metal sheets, rods, and other shapes needed for all sorts of products, from automobiles to computers. **Foundries** make cast metal parts and tools that are essential to both industrial and commercial users. **Heat treating** is directly related to metal production and secondary processing industries. Materials processed by heat treating include iron, steel, ferro-alloys, glass and other non-ferrous metals. **Powder metallurgy** is used to make ferrous and non-ferrous metal components from metal powders. These components are currently used in a variety of end-uses, such as automobiles, appliances, tools, aircraft, and motors, to name a few. **Welding** is used throughout the manufacturing and forming and finishing industries to join together metals, polymers, ceramics, and engineered composites.

End-Use Industries

The end-use industries rely on the intermediate products from manufacturing, forming and finishing to create finished products**. Computers** and **appliances**, for example, require materials from both the chemical (plastic components), metals (sheet metal) and glass (CRT, appliance windows) industries. **Construction** operations rely on structural materials that originate in the forest products, steel, aluminum and glass industries, and require various products created from chemicals and petroleum inputs (e.g., adhesives, asphalt paper, roofing tiles, paint). **Heavy machinery** and t**ransportation equipment** (automobiles, ships, trucks) require inputs from many basic industries as well as the forming and finishing industries. **Textiles** rely heavily on plastics and fibers produced by the chemical and forest products industries. Products made from **plastics and rubber** are created from polymer intermediates manufactured in the chemical industry using extrusion, molds, and other processes.

2.0 Industrial Energy Use Profile

Total Industrial Energy Use

The U.S. industrial sector consumed approximately 25 quadrillion Btus (quads) of energy in 2001. When the energy losses incurred during the generation and transmission of purchased electricity are included (about 7.6 quads), total energy consumption associated with industry rises to about 32.6 quads [EIA 2001]. This represents about a third of all the energy consumed in the U.S. every year.

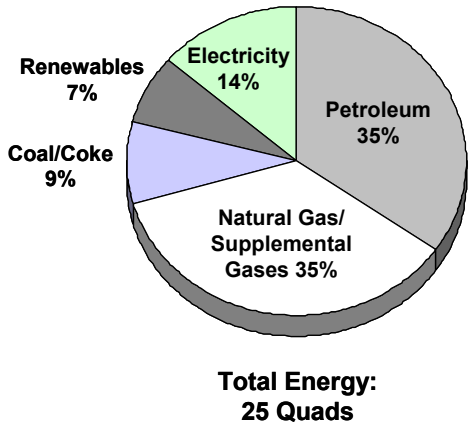

Figure 2-1. Total Net Energy Use in U.S. Industry

Natural gas, supplemental gases (petroleum fuel gas, LPG, byproduct gases), and petroleum (crude oil, residual and distillate fuel, refined products) are the largest sources of energy for the industrial sector (see Figure 2-1). Coal and coal products are used to a lesser degree. Direct purchases of electricity only account for about 10 percent of use. However, when the energy losses associated with electricity generation at utilities are considered, the total energy attributed to industrial electricity use is about 33 percent. Renewable energy sources such as wood, waste, and hydropower account for about 6 percent of energy use [EIA 2001].

Industry uses energy in two ways: energy is combusted for heat and power in industrial processes and facilities, or it is used in the manufacturing sector as a raw material (feedstock) to produce non-fuel products like asphalt, lubricants, wax, petrochemicals, plastics, fibers, and fertilizers. The bulk of energy use, about 70 percent, is combustible fuels and electricity (the focus of this report). Feedstock use accounts for the remainder, or about 7.3 quads of total energy [MECS 1998].

Sector-Specific Total Energy Use

Energy use patterns vary substantially among different industry groups, depending on the types of processes, whether the industry is facility-intensive, and the complexity of operations. As shown in Table 2-1, the manufacturing sector (basic industries) accounts for the largest portion of energy use, followed by materials, end-users, and forming and finishing operations. Total net energy use represents the direct use of fuels and electricity by the industrial sector. Total primary energy use includes offsite losses associated with the generation and transmission of electricity, and with the transport of fuels to the plant. It should be noted that several industrial sectors are not represented here, including printing, furniture making, coal products, and other miscellaneous sectors. A comparison of total net and primary energy for each sector is shown in Figure 2-2. The percent of primary energy attributed to losses is greatest in the forming and finishing and end-use sectors, where electricity accounts for 30-40 percent of net energy use.

Energy is used in the **materials** sector for mining and extraction equipment, heavy transport, pumping, drilling, beneficiation and various other operations. In the agricultural sector, energy is used for planting and harvesting, application of fertilizers and chemicals, irrigation, and drying and conveying of harvested products. Overall, natural gas accounts for the largest share of net energy use, about 37 percent. Diesel fuels comprise about 16 percent. Other fuels, some of which are produced on-site at mines and extraction operations, account for about 23 percent, and include light gas mixtures, oils and gasoline. Total energy use is about 3.7 quads, or about 15 percent of the total net energy used by the industrial sector.

Table 2-1 Total Energy Profile: Selected Industry Sectors[a] (trillion Btu)

	Residual Fuels	Distillate Fuels	Natural Gas	LPG/ NGL	Coal and Coke	Other	Net Purchased Electricity	Total Net Energy Use	Offsite Electricity Losses	Offsite Fuel Transport Losses	Total Primary Energy Use
Materials Sector											
Agriculture	0	339	77	221	0	214	221	**1072**	459	0	**1531**
Mining	0	250	167	0	77	16	243	**753**	505	15	**1273**
Oil & Gas Exploration	5	12	1101	0	0	615	112	**1845**	232	52	**2129**
Sector Subtotal	5	601	1345	221	77	845	576	**3670**	1196	67	**4933**
Basic Manufacturing											
Aluminum & Alumina	0	1	189	1	1	3	246	**441**	511	6	**958**
Cement	0	3	27	0	225	61	39	**355**	81	10	**446**
Chemicals	50	9	1984	51	284	749	602	**3729**	1251	94	**5074**
Food Processing	16	18	613	6	158	104	241	**1156**	501	28	**1685**
Forest Products	152	21	659	9	279	1825	327	**3272**	679	88	**4039**
Glass & Glass Products	3	0	194	1	0	2	54	**254**	112	6	**372**
Iron and Steel Mills	29	5	456	0	48	971	163	**1672**	339	45	**2056**
Petroleum Refining	70	4	948	33	0	2300	123	**3478**	256	101	**3835**
Sector Subtotal	320	61	5070	101	995	6015	1795	**14357**	3730	378	**18465**
Forming and Finishing											
Fabricated Metals	2	6	240	5	3	9	176	**441**	366	8	**815**
Foundries	0	1	136	2	0	31	63	**233**	131	5	**369**
Forging	0	0	33	0	0	0	8	**41**	17	1	**59**
Heat Treating[b]	0	0	337	0	0	0	121	**458**	251	10	**719**
Powder Metallurgy	0	0	9	0	0	0	7	**16**	15	0	**31**
Welding[b]	0	0	13	0	0	0	116	**129**	241	0	**370**
Sector Subtotal	2	7	768	7	3	40	491	**1318**	1021	24	**2363**
End Users											
Computers/Electronics	2	2	116	2	0	5	194	**321**	403	4	**728**
Plastic/Rubber Products	5	1	126	4	3	5	183	**327**	380	4	**711**
Construction	0	426	111	0	0	608	90	**1235**	187	34	**1456**
Heavy Machinery	1	3	100	3	6	4	96	**213**	199	4	**416**
Textiles	17	5	153	3	24	16	141	**359**	293	7	**659**
Transportation Equipment	5	15	210	4	29	30	195	**488**	405	9	**902**
Sector Subtotal	30	452	816	16	62	668	899	**2943**	1867	62	**4872**

Notes
a Energy for heat and power only; feedstocks are not included. Does not include printing, furniture-making, coal products, and a few other miscellaneous manufacturing sectors.
b Energy use overlaps with energy used in manufacturing sector; a total of all sectors is presented to avoid duplication.

Sources:
MECS 1998
Mining 2003
DOE 1991
DOC 1997
Crosscuts 2003
USDA 2001

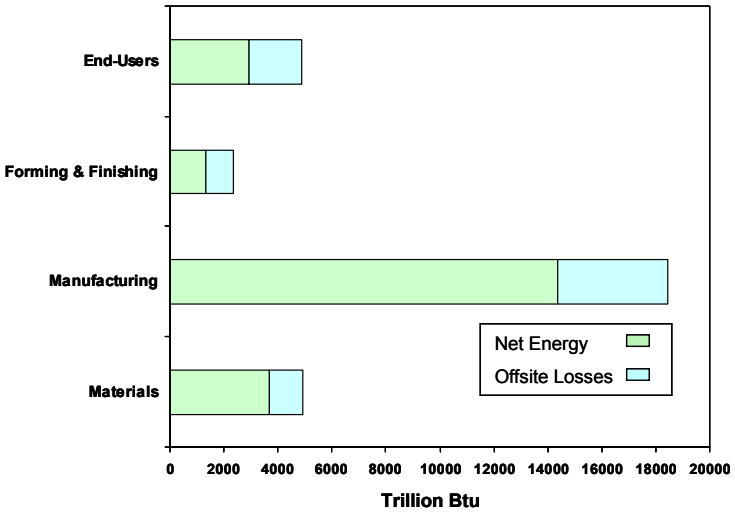

Figure 2-2. Comparison of Net Energy Use and Offsite Losses in Selected Industrial Sectors

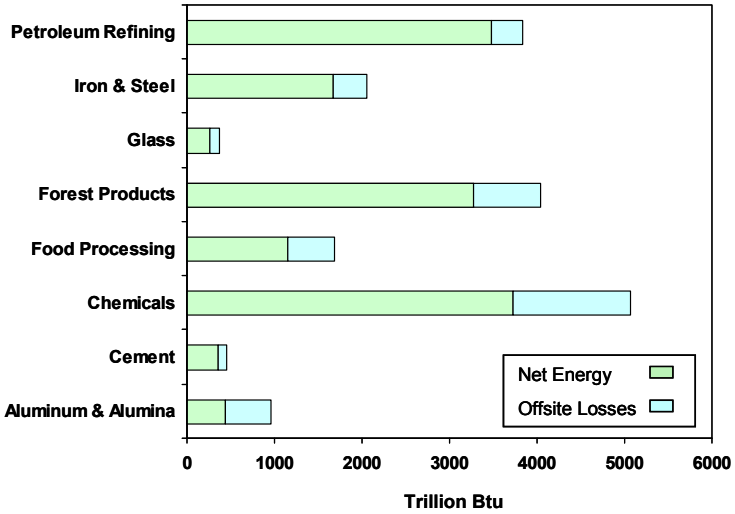

Figure 2-3. Comparison of Net Energy Use and Offsite Losses in the Manufacturing Sector

The **basic manufacturing** sector is highly diverse and energy patterns vary dramatically from industry to industry. In general, this sector is characterized by the intensive use of fuels and electricity for process heating and cooling. In the basic manufacturing industries, raw materials are often transformed into usable products through various physical, chemical, and mechanical conversion processes requiring very high temperatures and pressures or otherwise severe conditions. As shown in Table 2-1, about 14.3 quads of energy use are attributed to this sector, or about 57 percent of industrial use.

Figure 2-3 illustrates the various energy intensities of industries in this sector. Three industries – chemicals, forest products, and petroleum refining - are by far the largest users of energy in this sector. Natural gas is the largest purchased fuel source used by the industry, with over 35 percent of total net energy use. Most basic manufacturing industries are fuel rather than electricity-intensive, with average electricity use accounting for about 12-13 percent of the total.

Other fuel accounts for a large share of energy use, over 42 percent. This category includes byproduct fuels that are produced onsite. In the chemicals and petroleum refining industries these are light gas mixtures, liquefied gases, and a mix of oils and other combustible byproducts. In the forest products industry these are mostly byproducts of the pulping process (e.g., black liquor, bark, other wood byproducts). Blast furnace and coke oven gases are byproduct fuels used in iron and steel.

In **forming and finishing**, energy is consumed for fabricating, casting, forging, heat treating, machining, welding and other physical and chemical processes needed to assemble final and intermediate products. Total energy use for this sector is 2.4 quads per year, or about 10 percent of total industrial energy use. It should be noted, however, that some of these industries (notably heat treating and welding) are captive within the basic manufacturing and end-use sectors, so some duplication of energy is represented. When compared as a stand-alone category, energy use for forming and finishing is significant, and may be substantially under-reported as it is difficult to estimate energy use for some of the processes in use.

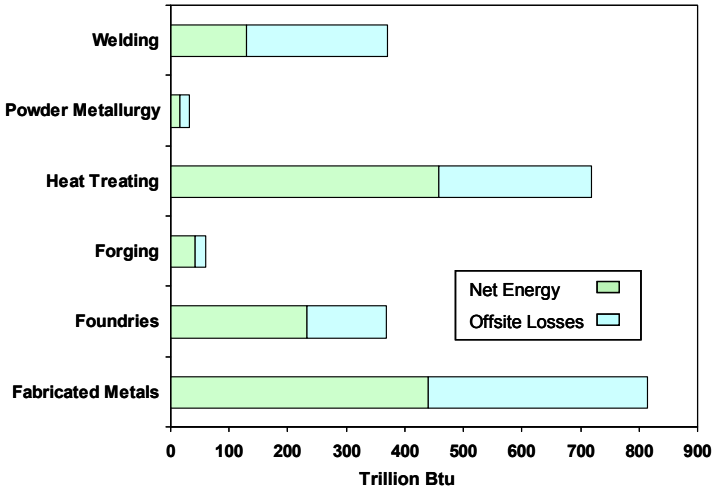

Figure 2-4. Comparison of Total Net Energy Use and Offsite Losses In Forming and Finishing

Figure 2-4 illustrates comparative use within this sector. Most forming and finishing processes are relatively electricity-intensive; in some cases electricity use accounts for more than 40 and up to 90 percent of energy use (metals fabrication, powder metallurgy, welding). Unlike manufacturing, byproduct fuels account for only a small portion of energy use. Fuel-based process heating accounts for a significant share of energy use in metals fabrication, heat treating, and in foundries. The primary fuel of use is natural gas, with very small amounts of diesel and other petroleum fuels used.

End-users consume energy in assembly and other manufacturing processes that create final products for use by all sectors of the economy. These processes are highly diverse; some are very labor-intensive, others are highly automated. Some have extensive facilities needs (large plants, warehouses); others have virtually no facilities and work is conducted outdoors (construction). As a result, energy patterns vary widely, with some end-users relying extensively on gasoline and diesel fuel, while others use large amounts of electricity or natural gas. Total net energy use for the end-use sector was calculated to be about 4.9 quads, or about 20 percent of total industrial use.

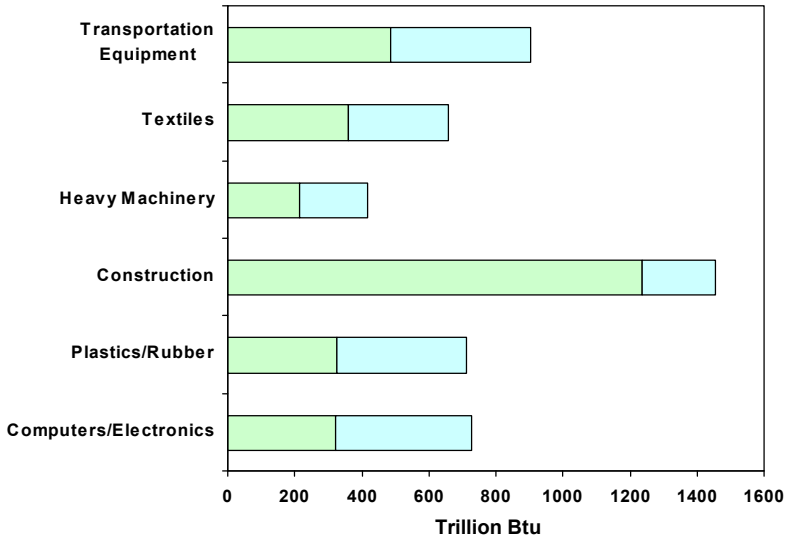

Figure 2-5. Consumption of Total Net Energy Use and Offsite Losses in the End-Use Sectors

A comparison of net energy and losses among end-users is shown in Figure 2-5. Construction is the largest energy consumer, followed by manufacturers of transportation equipment (automobiles, trucks, buses, ships, aircraft, railroad cars). Electricity accounts for the largest share of energy use, about 31 percent, followed closely by natural gas at 28 percent. Other fuels include mostly gasoline, with small quantities of byproduct fuels used.

Energy-intensive processes for selected industries are illustrated in Table 2-2. In general, industries that rely heavily on steam and process heat are among the most energy-intensive. The exceptions are agriculture, mining, and construction. Energy use in these industries is dominated by the use of diesel fuel and gasoline for combustion engine-driven equipment.

Table 2-2 Energy Intensive Processes in Selected Industries		
Subsector	**1998 Process Energy (Quads)**	**Energy-Intensive Processes**
Agriculture[1]	1.531	Combustion engine equipment (gasoline, gasohol, and diesel make up 75% of industry consumption)
Mining[2]	1.273	Diesel equipment for material handling (hauling), 37% crushing & grinding, 29% pumps, 8%
Oil and Gas Exploration	2.129	Natural gas: compression equipment; H_2O removal Oil: pumps
Aluminum & Alumina[3]	0.958	Electrochemical processes, 63%; other process heating, 23%
Cement	0.446	Rotary kiln (largest use of fuel; raw grinding (prior to calcination in kiln)
Chemicals[4]	5.074	Organic chemicals; 45%; inorganics, 11%; fertilizers, 8%; industrial gases, 5%. Major processes: separations (distillation, evaporation, crystallization) and chemical reactions.
Food Processing[5]	1.685	Evaporation/concentration, 25%; drying, 22%; chilling/cooling/refrigeration, 11%; heat treatment/pasteurization, 10%; cooking, 9%
Forest Products[6]	4.039	Pulp and paper: papermaking, 50%; pulping, 20%; chemical recovery, 20% Lumber and wood products: sawmills, 40%; veneer and engineered wood processes, 60%
Glass & Glass Products[7]	0.372	Melting and fining, 50%; forming, 29%
Iron and Steel Mills[8]	2.056	blast furnace, 40%; process heating (incuding electric arc and reheating furnaces), 25%; boiler fuel, 7%
Petroleum Refining[9]	3.385	Atmospheric and vacuum distillation, 35%; catalytic hydrotreating,19%; catalytic cracking, 12%; reforming, 15%
Foundries[10]	0.369	Melting furnaces, 55%; mold making, 12%; core making, 8%; post-cast activities, 7%; heat treatment, 6%;other, 12%
Computer/ Electronics	0.728	Assembly, fabrication, semiconductor/circuit board processes, laminating, melting, welding, electrolytic cells, drying, waste handling
Plastic/Rubber Products	0.711	Extrusion, injection molding, other forming processes
Heavy Machinery	0.416	Forging, stamping, bending, forming and machining to shape individual pieces of metal; welding of components.
Textiles	0.659	Dyeing, spinning
Transportation Equipment	0.902	Bending, forming, welding, machining, and assembling metal or plastic parts

*All percentages are approximate.

[1] 1997 Census of Agriculture, USDA National Agricultural Statistical Service
[2] Energy and Environmental Profile of the U.S. Mining Industry, US DOE Industrial Technologies Program.
[3] Aluminum Industry Analysis Brief: Energy Use, US DOE, Energy Information Administration, http://www.eia.doe.gov/emeu/mecs/iab/aluminum/page2b.html
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[8] Steel Industry Analysis Brief: Energy Use, US DOE Energy Information Administration, http://www.eia.doe.gov/emeu/mecs/iab/steel/page2b.html
[9] Energy and Environmental Profile of the U.S. Petroleum Refining Industry, Energetics, Inc. for the U.S. Department of Energy, 1998.

3.0 Carbon Generation

Carbon, in the form of carbon dioxide (CO_2), is generated by the industrial sector through the combustion of fossil fuels and some renewable energy sources such as wood and wood byproducts. Consequently, energy use and carbon emissions are highly correlated. Some industrial processes, such as the manufacture of lime and ammonia, also generate carbon dioxide and other greenhouse gases such as methane. Table 3-1 quantifies the extent of carbon emissions solely from the combustion of fuels in selected U.S. industries, in the form of million metric tons of carbon equivalents (MMTCE). Combustion-based carbon emissions are calculated based on carbon coefficients (MMTCE/trillion Btu) provided by the U.S. Department of Energy, Energy Information Agency [EIA 2001] (see Table 3-2).

Table 3-1 Carbon Emissions for Selected Industry Sectors

	Total Net Energy Use	Total Primary Energy Use	Carbon Emissions - No Losses (MMTCE)	Carbon Emissions - /w Losses (MMTCE)
Materials Sector				
Agriculture	1072	1531	19.8	28.1
Mining	753	1273	14.1	23.5
Oil & Gas Exploration	1845	2129	30.1	35.3
Sector Subtotal	3670	4933	64.0	86.9
Manufacturing				
Aluminum & Alumina	441	958	7.3	16.7
Cement	355	446	8.1	9.8
Chemicals	3729	5074	61.7	86.2
Food Processing	1156	1685	20.1	29.7
Forest Products	3272	4039	74.1	88.1
Glass & Glass Products	254	372	3.9	6.0
Iron and Steel Mills	1672	2056	62.8	69.8
Petroleum Refining	3478	3835	57.2	63.8
Sector Subtotal	14357	18465	295.3	370.0
Forming and Finishing				
Fabricated Metals	441	815	7.2	13.9
Foundries	233	369	3.8	6.2
Forging	41	59	0.6	0.9
Heat Treating [a]	458	719	7.1	11.8
Powder Metallurgy	16	31	0.3	0.5
Welding [a]	129	370	2.3	6.6
Sector Subtotal	1318	2363	21.2	40.1
End Users				
Computers/Electronics	321	728	5.4	12.8
Plastic/Rubber Products	327	711	5.5	12.5
Construction	1235	1456	23.7	27.7
Heavy Machinery	213	416	3.5	7.2
Textiles	359	659	6.2	11.6
Transportation Equipment	488	902	8.4	15.9
Sector Subtotal	2943	4872	52.7	87.7

a Energy use and carbon emissions overlap with manufacturing sectors; total for all sectors is not presented to avoid duplication of emissions.

Table 3-1 also provides total carbon emissions when the losses associated with offsite energy generation and transport are considered. In those industries that are electricity-intensive, due to the relative inefficiency of current electricity generation technology, carbon emissions are substantially higher, and in some cases nearly double.

Energy consumption (and the associated carbon emissions) is impacted by fluctuations in economic growth, the weather, the carbon and energy intensity of the economy, and changes in energy prices. In general, industrial production and related energy consumption declined in 2001, due to drops in the total industrial production index (3.9 percent) and a decrease in manufacturing activity (4.4 percent). The drop in the manufacturing index was the largest in recent years, surpassing the 2.4 percent decline experienced during the recession of 1991. Output declined in 2001 in the six energy-intensive basic industries (primary metals, pulp and paper, stone, clay and glass, food, chemicals, and petroleum) which historically account for about 65 to 70 percent of total industrial carbon dioxide emissions. The declines in industrial output and manufacturing activity contributed to a decline in industrial emissions of about 5.4 percent (from 478.4 million metric tons carbon equivalent in 2000 to 452.4 million metric tons in 2001) [preliminary estimates, EIA 2001]. These estimates include both combustion and non-combustion greenhouse gas emissions. As the largest fuel consumer, the basic manufacturing sector generates the largest share of greenhouse gas emission in industry, nearly 300 MMTCE or about 65 percent of the total.

Table 3-2 Carbon Coefficients for Combustion of Fuels (MMTCE per trillion Btu)

Carbon Coefficient	2001	1998
Electricity	0.01808	0.01808
Natural gas	0.01447	0.01447
Petroleum - Residual Fuel	0.02149	0.02149
Petroleum - Distillate Fuel	0.01995	0.01995
Petroleum - LPG	0.01699	0.01699
Gasoline	0.01934	0.01933
Coal	0.02563	0.02579
Biomass	0.02612	0.02612
Blast Furnace Gas	0.06124	0.06124
Coke Oven Gas	0.01179	0.01179

Sources: EIA 2001, Steel 2002, EPA 2001

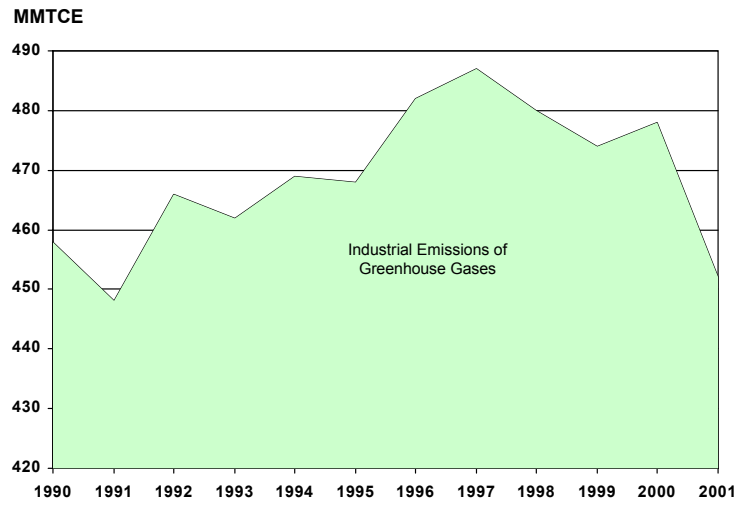

Figure 3-1. Historical Emissions of Greenhouse Gases from U.S. Industry [EIA 2001]

As shown in Figure 3-1, greenhouse gas emissions from the industrial sector have declined considerably over the last decade from their peak in 1997 of nearly 490 MMTCE. This is directly correlated to the economic slowdown and industry switching to the use of fuels which contribute fewer emissions of carbon when combusted (lower carbon coefficients). As Table 3-2 shows, the higher the carbon coefficient, the more greenhouse gas emitted by combustion of that fuel.

Use of natural gas by U.S. industry, for example, increased by 13 percent between 1990 and 2000, while use of coal declined by more than 20 percent. However, with the volatility in the supply and price of natural gas experienced over the last two years, the trend to use cleaner natural gas may reverse to some extent as prices put pressure on manufacturers.

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